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ROOT STUDIES I: Preliminary Attempts to Study the Root Systems of Mature Ponderosa Pines

By

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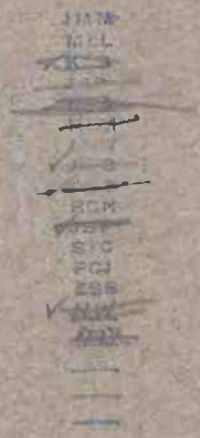

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The symptomatology of ponderosa pine health, as seen in the crown and stem of trees, has been an important study in ponderosa pine management for nearly two decades. Recently, the work of diagnosing current tree health has led to the need of evaluating symptoms and their combinations so that they can be weighted in determining the risk of individual trees. An understanding of the cause for certain of these symptoms would undoubtedly aid the evaluation work by segregating the general from the specific and the unimportant from the important.

Up to the present time, most of the work on causes of ponderosa pine decline has been concentrated on the biological and climatic factors in so far as they affect the tree crown and stem. Recently the work of Secrest, MacAloney, and Lorenz[65] with hemlock, Erlich[18] with western white pine, and Salman,[53] West,[77] and Johnson[30] with ponderosa pine gives good indication that some progress in this field can be anticipated by widening the scope of study to include tree roots.

An investigation of ponderosa pine root systems was undertaken by the Portland laboratory during the 1941 season. The object of the study was twofold, namely: (1) To correlate root condition with crown condition throughout the range from healthy to unhealthy trees; and (2) to determine the effect of edaphic factors in producing the various health symptoms. Thus by determining condition in the one case and cause and effect in the other, the two can be combined eventually to prove the importance or unimportance of the factors included in the study.

The entire experiment has been catalogued under the general heading, "Root Studies," but the two objectives are being handled in separate reports, which appears to be the most feasible manner of presenting plans and results. "Root Studies I" includes only root examinations undertaken to meet the first objective, and "Root Studies II" includes only work on edaphic factors studied under the second objective.

This report deals only with material under the heading "Root Studies I". It is primarily a summary of the literature in the field to provide a handy reference work throughout the course of the investigation. It also contains an account of preliminary field observations and a general plan of procedure for completion of the study.

Review of Literature

A vast wealth of published material is available concerning plant roots, and, surprisingly enough, much of it deals with the roots of forest trees. This literature has been very helpful in giving a general understanding of root habits and development, and in pointing out what may be expected in the way of normal anatomy, morphology, and physiology of roots.

Root Anatomy

That part of the plant axis which normally develops beneath the surface of the soil is commonly called the root as distinguished from the aerial portion of the axis, the stem. From the standpoint of the anatomists[16] however, there are additional differences between root and stem which are fundamental in that they are concerned with the arrangement and method of development of the primary tissues. The primary xylem of the root is exarch as contrasted with the endarch condition of the stem, and the root has radial arrangement of vascular tissue, whereas the bundles of the stem are collateral, bicollateral, or concentric. Roots differ further from stems in that they do not have appendages comparable to leaves, do not give rise directly to flowers, lack stomata, and form lateral branches from relatively permanent tissue in the pericycle rather than from the promeristem at the growing point. Other differences are the usual presence of the root cap, a structure entirely lacking in stems; the almost universal occurrence of an endodermis, which is frequently lacking in stems; and the usual pericyclic origin of the initial periderm layer in roots, a condition found only rarely in the normal aerial axis.

The secondary vascular tissues of the root do not differ fundamentally from those of the stem. Thus, in the examination of ponderosa pine roots, we are primarily concerned with tissues very similar to those of the stem. Such differences as do occur are apparently the result of adaptations to differences in function. Thus, the xylem of roots, as compared to that of stems, has larger and more numerous vessels with thinner walls, fewer fibers, more parenchyma, and larger, more abundant rays; the phloem has sclerenchyma and storage parenchyma. The arrangement of xylem and phloem elements in the secondary tissues of roots is fundamentally the same as that found in the stems of the same species.

In stems, the primordia of the branches and leaves are laid down in the primordial meristem at the growing point, according to a definite plan. In roots on the other hand, no branches or appendages of any kind are laid down in the meristem at the root tip, and when lateral roots are developed, they are initiated in relatively permanent tissues and without regular order with reference to each other except that of general acropetal succession. In angiosperms and gymnosperms, root branches arise in the pericycle opposite the xylem strands. This restriction of lateral root formation to regions opposite the xylem causes roots to appear in vertical rows--as many rows of laterals being formed as there are rays of xylem. This appears to hold generally for a species but is not readily discernible in plants grown in soil because of the displacements due to root pressure on the soil. According to Hatch and Doak,27/ the long roots of Pinus are diarch or polyarch and branch racemosely, whereas the short roots are monarch and branch dichotomously. They also record that the root cap is present on long roots and absent on short roots.

There are no concentric rings of primary tissues in roots similar to those found in stems because of the radial arrangement of the strands of primary xylem and phloem. When secondary thickening does occur, the cambium originates as bands or strips of meristem and from the ends of these first formed cambium segments, the layer of initials is extended laterally by the differentiation of the parenchyma between the primary phloem and xylem strands until the segments of the cambium meet.

Cambial development frequently does not take place in roots as quickly as in the stem of the same plant. In fact, in many of the smaller feeding roots, cambium may not be formed at all, even though secondary growth occurs abundantly in the stem and larger roots. This condition is apparently an adaptation to the function of the root as an absorbing organ, since wherever extensive secondary growth arises, the root is no longer capable of absorption in that region because of the destruction of the root hairs, endodermis, and cortex, and because of the usual immediate formation of periderm.

Root Morphology

Publications in the field of root morphology are particularly abundant. Quite naturally mention of plant roots appears early in the literature, but it was not until 1852 that a comprehensive consideration of tree roots was attempted by Theodore Hartig,[25] who proposed the first classification. This is particularly noteworthy because portions of this classification are used by writers today. His separation of long and short roots was the first recognition of the differentiation in roots according to their function--whether supporting or feeding roots. Toumey[70] described and classified the seedling root systems of many of the more important eastern species. These were divided into three main groups: (1) Generalized, having both wide spreading lateral roots and deeply penetrating vertical roots; (2) specialized lateral, having mainly widespreading lateral roots; and (3) specialized vertical, having mainly deeply penetrating vertical roots. Laitakari[32] classified root systems (particularly Pinus sylvestris) into horizontal or surface root systems and vertical or deep root systems. He further subdivided the horizontal system into main surface roots, horizontal roots of the second class, horizontal roots of the third class, etc., depending on the manner of their branching. Vertical branches from the horizontal roots he called inner-deep-roots if close to the base of the tree, and scattered-deep-roots if farther removed. The tap root (if present) and its branches, plus the inner deep roots, he called the central deep-root system. He also recognized dwarf roots, termed short roots by Hartig,[25] Hatch,[27] and others and feeding roots by Dunning.[15]

This classification by Laitakari, coupled with the term feeding roots for the short and mycorrhizal roots, appears to be most satisfactory for use with ponderosa pine according to present preliminary observations, and will be used until need for revision appears. Indeed, the generalized type of root system described by Laitakari for Pinus sylvestris appears to be characteristic of the genus according to work by Cheyney,[10] McQuilkin,[39] and Heyward.[28]

Little is known concerning the extent of the horizontal roots and penetration of deep roots in mature trees. Laitakari[32] recorded a horizontal root of 77 feet from Scotch pine. Heyward[28] found a horizontal root on longleaf pine to extend 71½ feet, at which point it changed abruptly to a vertical direction and went down 3½ feet. The end of this root was 51 feet in a straight line from the root collar. Heyward reported that the taproot of this tree penetrated

13 feet 4 inches into the ground, where it branched into two 3-inch roots which penetrated to a depth of 14 feet 2 inches. Several "cord-like" roots one-quarter to one-half inch in diameter continued on downward but were not followed. From this meager information, we can conclude that the root systems of mature ponderosa pines will be found to extend for rather long distances.

Since the primary functions of roots are absorption and anchorage, it is logical to expect specialization to adapt them better to meet these requirements. Modifications toward improved absorption and conduction have already been mentioned in the discussion of root anatomy and will be discussed further under root physiology. Probably the most obvious single modification toward improved anchorage is the thickening of roots in a vertical direction, particularly near the base of the tree. Rigg and Harrar[50] attributed the lack of excessive windthrow in sphagnum bogs to result from greater vertical thickening, longer horizontal roots, and more abundant root fusions. Büsgen and Münch[6] and McQuilkin[39] attribute vertical thickening to root modification to attain greater strength. Laitakari[32] found flattened roots to be most common near the surface of the soil and on the side of the prevailing wind. Rasdorsky[47] was able to produce vertical thickening by stem movement. Knight,[31] working with apple seedlings, concluded that greatest growth takes place where there is greatest movement. Burns[5] found that pine trees bent over and fastened in that position produced eccentric growth on the lower side which he considered a morphogenic response to gravity.

It is the general opinion that vertical thickening in roots results from movement of the stem by wind. The value of this growth in roots is obvious when it is considered that the strength of beams of varying transverse sectional shapes, approximates the square of the vertical dimensions when the horizontal dimensions remain the same.

The question of reciprocity between root and crown is an important one in this study of ponderosa pine root systems. Laitakari[32] found poor root systems developed on the side of the prevailing wind and that the crowns were also poorly developed on the same side. However, this was true only in older trees. Stevens[67] concluded that in general trees with vigorous tops possessed rapidly growing root systems. He wrote, "No tree can achieve and maintain dominance in an even-aged stand unless its root system is of corresponding superiority." McQuilkin[39] also found poor top development to be associated with inferior root systems.

Finally in the discussion of root morphology, it should be mentioned that the type of system and the extent of tree roots appears to depend on age. McQuilkin[39] pointed out that young trees develop mainly vertical roots; then, as the top develops, the horizontal system is extended; and finally as age advances, the supporting roots are thickened and numerous branches are produced to develop a dense system.

Root Physiology

Since absorption of water and nutrients from the soil is the primary physiological function of roots we may safely assume that the extension of root systems to contact more abundant supplies of moisture and nutrients is of critical importance, particularly in the study of high risk ponderosa pines. Absorption by the root takes place for the most part by diffusion through the walls of the root hairs--when root hairs are present. Water may also be absorbed through the epidermis of the root in the region distal to the zone of root hairs, and the students of mycorrhizae point out that in forest trees, the symbiosis of fungi and roots plays an all-important role in this connection.

Lateral roots are commonly formed most abundantly in the region just behind the zone of root hair growth. As they extend at right angles to the axis of the root from which they are derived, and in turn produce root hairs, and later, lateral roots, it is apparent that the branching system thus formed is very effective in reaching all parts of the soil.

Thus, the development and growth of roots by trees is of considerable significance. It is a measure of the ability of the tree to provide the supply of nutrients and moisture necessary for the proper growth of its crown, and it is also indicative of the ability of the tree to invade new areas and to maintain itself against competition.

Numerous factors have been recorded as affecting root development. Although the physical properties of the soil must exert the first strong influence on root form, very little is known of its effect. Haasis[21] reported that on clayey soils, the roots of ponderosa pine seedlings were longer and that the ratio between top and root was smaller than on loamy soils, although he attributed this to a moisture relationship rather than to soil texture. Laitakari[32] found much root branching in good soil and no branching in poor soil. Pessin[44] reported that root development is restricted when roots contact hardpans and Sweet[69] recorded the same for various compact soil layers. That hard, compact soil layers limit the extent of root systems has also been observed by Weaver[73-74-75-76] and Crist.[75-76] Scholz[54] reported the superiority of clay loam over heavy clay loam or clay soils for growing red and chestnut oak. Harper[22] found that in regions of restricted precipitation, fine textured soils were beneficial to tree growth, providing the soil particles were not too fine.

The effect of soil composition on root development, in so far as necessary soil nutrients are concerned, has been studied by many investigators, particularly with crop plants. Weaver, Jean, and Crist,[73-74-75-76] Miller,[41] Laitakari,[32] and Lutz, Joseph, and Little[36] are all in accord in the conclusion that fertile soils cause a greater amount of root branching but retard normal penetration into the soil below, so that actually the more abundant nutrients increase the top more in proportion than the roots. Thus, the ratio of roots to tops tends to be smaller in fertile than in infertile soils.

Harris[23] contended that the ratio of roots to tops is affected more by a change in water content than by a change in the amount of nutrients. Reed[49] found that a deficiency of soil moisture limited root growth at times during the summer months, although shoots of the same trees were growing very rapidly at those precise times. Biswell[3] reported that trees in shade produce greater root systems owing to the fact that transpiration is greater in the shade than in the sun. Holch[29] also reported this moisture relationship resulting indirectly from light. Gail and Long[20] found that lateral roots of P. ponderosa went into the soil more obliquely than those of P. contorta and that the lateral roots of ponderosa were more abundant and regularly spaced. They concluded that this adaptation explained the presence of lodgepole on the more moist sites and the ability of ponderosa to

withstand dry sites. Turner,[71-72] working with southern shortleaf pine, concluded that soil moisture dominates all other factors in governing root and shoot growth. Nedrow[43] found that the greatest production of both roots and tops occurred where competition of plants was for light only and least where competition was for both light and water. The greatest production of roots in relation to top occurred where competition was for water and least where competition was for light only. He concluded that water was the dominant factor. Miller[40] concluded that the lateral extension of plant roots was governed by two primary factors, rainfall and the density of the stand. The reduction in lateral extension is directly proportional to increases in both of these factors.

Since the beneficial effect of mycorrhizae has recently been established, it is imperative to discuss this important symbiotic relationship in any consideration of tree roots and their nutritional and moisture relationships. The mineral salt theory of mycorrhizae abundance propounded by Stahl[66] appears to have been well substantiated by the work of Rayner,[48] Hatch,[26] and Mitchell.[42] These workers found that mycorrhizal fungi were not influenced by the amount of available nitrogen, but appeared under conditions of poverty in mineral salts. An important piece of work in this connection was contributed by Young[81] who found that pines inoculated with pure cultures of mycorrhizal fungi grew normally and that all uninoculated seedlings died. It is to be expected, therefore, that trees with mycorrhizal short roots are better able to compete for dominance in the stand and are more likely to survive under conditions of low mineral salt concentrations.

It has been shown by Cannon,[8] Free and Livingston,[19] and Bergman[2] that different species of plants vary widely in their response to variations in the amount of oxygen in the soil and that these differences in responses are quite as significant as the responses to available water and temperature. Interference with the process of respiration apparently causes injury and eventual death of roots owing to the exclusion or depletion of the oxygen supply of the soil. However, the minimum oxygen supply is not a fixed amount but varies directly with temperature change. The greater physiological activities of the plant at higher temperatures demand a greater supply of oxygen in the soil atmosphere. Cannon[7] found that at constant partial pressure of oxygen in the soil, the growth ratio varied with the temperature; and when the supply of oxygen was variable, but the temperature constant, it varied with the amount of available oxygen.

According to Eckerson,17/ "Heat does not act as a stimulus, but by affecting permeability is a direct factor in producing root curvatures, so that thermotropism is not to be considered a tropism, but a turgor movement." She found that root curvatures varied with the temperature and the plant species due to the fact that permeability of the root cells to dissolved substances also varied with the same factor. Hence, when temperatures prevailed which caused the cells to be more permeable, there was a consequent reduction in turgidity in the responding cells on one side of the root so that there was a mechanical curvature in that direction. Thus, temperature is effective in several ways.

The matter of competition between trees and other plants in the same association introduces another very complex set of factors. Probably the simplest expression of competition between trees is that given by Stevens67/ who believed that dominance of crowns expresses itself at an early age, and almost from the start certain individuals are noticeably more thrifty than the rest. He found that in these thrifty individuals, the height growth was greater, the crowns were broader, and when the stand closed, these trees soon overtopped the others. Stevens' belief in inherent dominance was based on the fact that in experimental plantings, growth of roots and shoots was good or poor regardless of the density of planting. Cheyney9/ also concluded that the position of roots had little effect on growth. Probably the greatest support of this theory is found in the work of Swarbrick and Roberts68/ who discovered that when a scion is grafted upon seedling roots, the variety of the scion determines the character of the roots developed. They concluded that the only apparent explanation lies in inherent individual variation and that some trees possess a disposition toward vigorous growth, while others do not.

Even accepting the theory of inherent dominance, consideration must also be given to the effects of those factors discussed previously as well as to the effect of one plant upon another. It has been known for centuries that one species of plant may have a detrimental or beneficial influence upon other plants of the same or different species that are growing in close proximity to it or that follow it in succession. For example, certain grains produce better when grown in combination than when grown separately,

grapes grow well in association with elm trees, and the beneficial effect of black locust on other trees in the same stand is well known to foresters. On the other hand, it has long been a matter of common observation that the soil becomes more and more unproductive to a given crop that is grown continuously upon it and also that the preceding crop may have a detrimental effect upon the succeeding one of a different species. Finally, it has been observed, especially in comparatively recent years, that plants growing in close relationship may have a detrimental effect on each other that cannot be wholly attributed to the competition of these plants for nutrients, moisture, air, or sunlight.

The detrimental influence of one plant or crop on another has been attributed to three general causes: (1) The depletion of nutrients in the soil so that there is not a sufficient supply for adjacent plants or plants which follow; (2) the production in the soil of compounds by decomposition processes that are deleterious to the roots of plants with which they come in contact; and (3) the excretion of toxic substances by the roots of one plant which are injurious to the roots of other nearby plants or to those which follow.

Concerning the first of these, Livingston,[35] and Schreiner, Skinner, and Reed[57-58] showed conclusively that the divergent effect of crops on those which follow seems not to be attributable, at least principally, to differences in the amount of nutrients removed by previous crops. That is, the smallest yields may not occur after the crop which removed the largest amount of even the most needed nutrient.

Regarding the second, it now appears to be universally accepted that the productivity of the soil may be decreased by reason of more or less complex organic substances that may be produced in it. Schreiner, Skinner, Shorey and Reed[57-58-59-60-61-62-63-64] isolated many organic compounds from the soil and their lists include many substances which commonly result from the decomposition of animal and vegetable matter and which are toxic to plant growth. The action of these seems to be neutralized or counteracted by fertilizers --thus, the common concept that unproductive soils are deficient in nutrients.

The subject of toxic secretions by plant roots has been given but little attention, and that comparatively recently in spite of the fact that as early as 1858 Liebig[34] and two years later Sachs[52] reported the dissolving action of roots on limestone. It was later found by several workers that under normal conditions of soil aeration, carbonic acid is the only one excreted by roots. If, however, the oxygen supply is cut off or is limited, organic acids only are produced. For example, the roots of buckwheat and barley produced formic and acetic acids under limited supplies of oxygen, while the roots of oats and maize under like conditions excreted formic acid and the roots of beets, oxalic acid. These organic acids arise from incomplete oxidation and under normal conditions of soil aeration would be oxidized to carbon dioxide and water. It has also been found by Schreiner and Sullivan[55-56] that roots have both oxidizing and reducing power. These actions can go on concurrently, but usually reduction is greatest in young plants and oxidation greatest in older plants. Reduction is mostly intracellular while oxidation is mostly extracellular. Oxidation is the more important to continued growth of the plant. Thus, most of the work on toxic secretions or excretions by roots appears to support the belief that under normal conditions toxic soil substances result from decomposition and not from secretion.

Obviously there are many factors at work inhibiting and stimulating root development, both singly and in combination with each other. It is these complex relationships which will make it extremely difficult to interpret the results of soil and root studies, particularly as to causes, because while physical forces operate in one case, physiological processes are also operative, and the two may be in progress at the same time. However, it is evident from the preceding review of available literature that roots play an important role in the growth and continued health of plants. The apparent conformity of root vigor to crown vigor is particularly significant in this study of susceptibility of ponderosa pines to western pine beetle attack. This fundamental correlation between root condition and crown condition in ponderosa pines can be determined without becoming involved in complex relationships of interacting factors. Not only can this be ascertained, but it is imperative to do so before any great amount of work is done with causes.

Ponderosa Pine Roots

Some initial work has been done in comparing the root systems of low and high risk ponderosa pines. Johnson[30] examined partial root systems of six trees by excavating them with hand tools. He stated, "From these notes it appears that even in the root systems of Risk 1 trees there were quite a few dead roots. Such a condition may be a normal one. The root system of the one Risk 4 tree, however, was in noticeably poorer condition." He also reported on the root systems of five additional trees examined by Salman[53] and West.[77] In these examinations, one low and three high risk trees had extensive and apparently healthy root systems, whereas the fifth, a tree of high risk, had a root system which was "much reduced and apparently abnormal". Thus, all of the low risk trees and three of high risk possessed root systems considered to be in good condition, while only two high risk tree root systems were in poor condition.

These findings would indicate that either root systems of high risk trees are not necessarily poorer than those of normal trees, or that there are other critical characters besides abundance of living roots. Since other workers have found reciprocity between crown and roots, the assumption is that the search must be for other characters. Secrest[65] et al. found this difference to be in the root tips, which were dead and gnarled on decadent trees.

Plan and Procedure of Preliminary Work

The object of the preliminary work was to develop the technique of exposing mature ponderosa pine root systems and to make a sufficient number of examinations to permit an informed planning of subsequent work.

In the development of technique, the work of Dunning[15] and Secrest[65] et al. left little to be done except to improve in ability and skill through practice. The Berkeley laboratory loaned a Fairbanks-Morse gasoline pump (fig. 1) and hose equipment for this work. This pump was capable of delivering 600 gallons of water per hour at 100 pounds pressure at the pump.

The procedure was essentially the same as that used by Dunning. The duff and litter were first removed with a rake from the area to be washed. A drainage ditch was then washed parallel to the slope to carry off the mud and water as the washing proceeded. For this preliminary work, no transect lines were marked to locate root position; however, this is advisable, and will be done in future work when total root systems are to be exposed. Washing was stopped regularly as roots were exposed to determine whether they were living or dead before they were subjected to too much drying from exposure.

Records were made as to whether the roots were living or dead, the number and diameter of roots at the root collar, the depth below the surface of the soil of each root at the root collar, the angle of penetration (angle from horizontal) of each root, and the number of feeding roots per lineal foot of root.

Results of Preliminary Work

Partial root systems of six ponderosa pine trees were examined by the method outlined above. These trees were paired, so that one low and one high risk tree were included in each pair. Summarized results of these examinations are shown in table 1.

Table 1: Comparison of root system of low and high risk trees

Comparison of main horizontal roots	Low risk	High risk	Significance of difference
Average number	12.3	11.6	none
Average diameter	6.5	5.3	none
Percent dead	8.1	11.4	none
Average number feeding roots per foot	3.7	3.3	none
Average angle of penetration	48	32	high
Average depth in inches	7.8	4.5	high

Two significant differences are shown in table 1. The angle from the horizontal at which the roots penetrate the soil where they branch from the root collar, and the depth of the root below the soil surface where it branches from the main axis, are both greater in low than in high risk trees (figs. 3 and 4). This fits in closely with Hall's findings regarding available moisture at different soil depths and would indicate that even if root systems were equal in number and size of roots, the amount of moisture available to low risk trees would be much greater than that available to high risk trees.

It is also to be noted that although no significance was found for differences in number, diameter, and mortality of main horizontal roots, nor for the number of feeding roots, there are slight differences (fig. 5) which are always in favor of the low risk trees. It is possible that some of these may show significance when a larger number of examinations have been made.

It is now evident that the 1941 examinations were inadequate in two respects. First, in the light of what has been learned of mycorrhizal roots and the general functions of all short feeding roots, a more intensive examination of them should have been made. Second, the root tips of main horizontal roots as well as those of laterals and sub-laterals should have been examined more carefully, since these are important active root areas, particularly in so far as moisture absorption is concerned.

Although these examinations are few in number and somewhat inadequate, as has been pointed out, they do indicate that critical differences will be found between low and high risk tree root systems. It seems equally obvious that the ponderosa pine studies would be greatly benefited if it were determined what these differences are, their cause and effect, and with what crown characters they are associated.

Recommendations for Future Work

If and when this study is continued, the following plan of work is recommended:

Equipment

During the 1941 work it was soon realized that the pump was providing a sufficient pressure for the needs of root washing, but that the volume of water was inadequate to carry off the washed soil. This necessitated a great deal of non-productive time spent in cleaning the drainage ditches. Actually, five times the gallonage obtained last season is needed. Although it is desirable to point out these inadequacies in a contemplated work plan, it appears impractical to invest in an expensive new pump or other supplemental equipment which will be used only for such a comparatively short period. Since removal of mud is the only serious need, it is possible that washing on a steeper slope, or a supplemental irrigation ditch or flume to bring additional water to the excavation, will solve the problem. This is the only major equipment change contemplated in future work.

Procedure

On the basis of findings in the preliminary work, it is judged unnecessary to wash out entire root systems or large portions of them. Only sufficient washing will be done at the root collar to determine the following:

A - Main horizontal roots
- 1 - Number
- 2 - Size
- 3 - Number living and dead
- 4 - Depth of branching from main axis
- 5 - Angle of penetration

B - Dead areas at root collar
- 1 - Location
- 2 - Extent
- 3 - Cause

Following these determinations at the base of the tree, a sample of five main horizontal roots will be examined completely to determine:

A - Branching
  1 - Lateral branches
    a - Number
    b - Size
    c - Living and dead
  2 - Vertical branches
    a - Number
    b - Size
    c - Living and dead
B - Feeding roots
  1 - Normal feeders
    a - Number
    b - Living and dead
    c - Number tips
  2 - Mycorrhizal roots
    a - Number
    b - Living and dead
    c - Number tips
C - Main root tips
  1 - Number
  2 - Living and dead
  3 - Number mycorrhizal

Sampling problems worked on an empirical basis with the six trees examined last season show that a sample of five main horizontal roots is sufficient. This will need to be checked further on the basis of more detailed examinations of feeding roots and root tips. Sampling problems will also be worked to determine the minimum sample necessary in determining feeders, mycorrhizal roots, root tips, etc., on each of the main horizontals examined.

Since these root data are primarily for comparison with crown condition, detailed crown descriptions also will be recorded for each tree. This description will include tree class, risk class, and code number for the Portland records and will also include a description of current health symptoms according to the standard used by the Berkeley laboratory for these records. This will permit tying in root condition with the symptom evaluation work at both laboratories.

Summary

Recent studies of the root systems of decadent pines give good indication that the ponderosa pine studies would be benefited if the study of decadence causes were expanded to include the effects of edaphic factors.

A review of the literature discloses that root form is quite specific and in addition that there is considerable reciprocity between the crown and root system.

Anatomical, morphological, and physiological adaptations are found in tree roots to fit them better for primary functions of anchorage, absorption, and storage.

It is also apparent in the literature that root development is of critical importance to continued plant growth. It is imperative that root development keep pace with crown development.

Factors reported as affecting root development are: physical and chemical properties of the soil, soil moisture, mycorrhizae, soil gases, heat, toxic decomposition residues, competition, beneficial plant associates, and heredity.

Many of these factors are active at the same time and may interact upon each other so that very complex relationships occur.

In a preliminary field examination, the root systems of six mature ponderosa pines were examined--three high risk and three low risk trees in pairs.

Two significant differences were found between high and low risk root systems. In the low risk trees, the roots branch from the main axis deeper below the soil surface and penetrate the soil at a greater angle than the roots of high risk trees.

Additional slight differences were found, but they were not statistically significant. These differences were that high risk trees had fewer roots of smaller size, a greater percentage of dead roots, and fewer small feeding roots per lineal foot.

Recommendations for future work in this study are appended to this report.

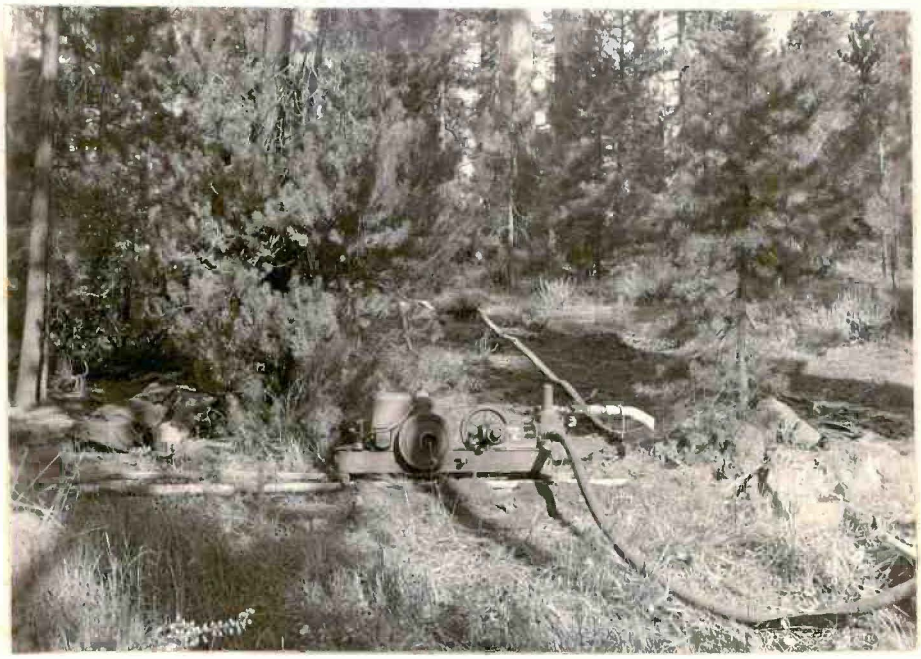

Figure 1.—Fairbanks-Morse pump used in the root washing work

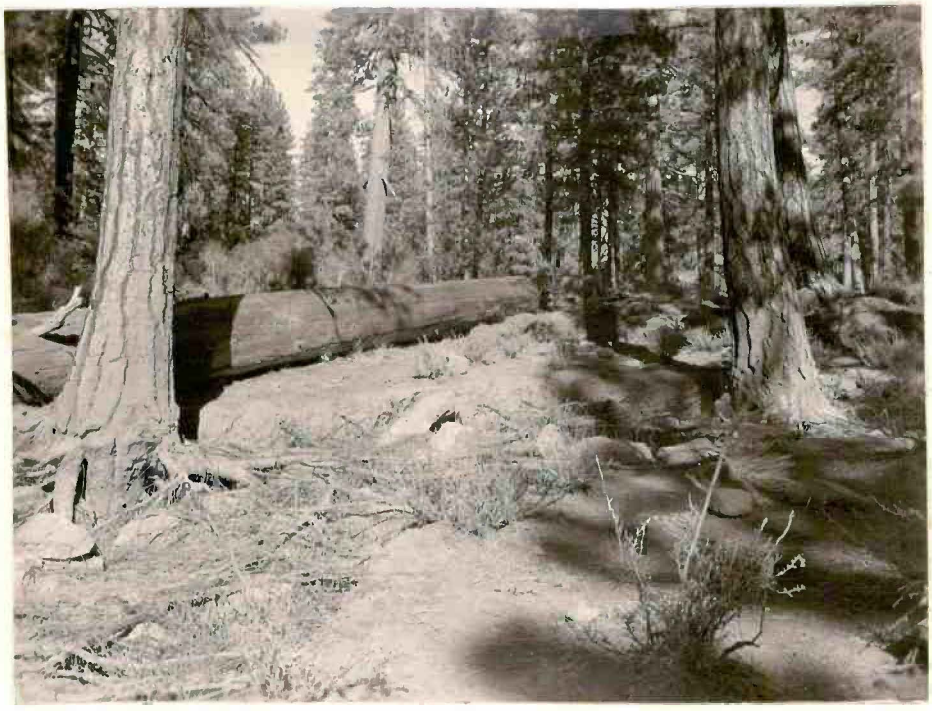

Figure 2.—A pair of trees showing partially exposed root systems

Figure 3.—Root crown of high risk tree shown at left of figure 2. Note shallow roots and almost horizontal branching.

Figure 4.—Root crown of low risk tree shown at right of figure 2. Note deeper branching and wider angle of penetration.

Figure 5.—Root crown on another of the high risk trees. Note tremendous tap root and small number and size of main horizontal roots.

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